INTERNATIONAL PROJECT HARMONIZATION FOR SFR DEVELOPMENT

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I. INTRODUCTION

In January 2008, the U.S Department of Energy (DOE), the French Commissariat a l'Energie Atomique (CEA) and Japan Atomic Energy Agency (JAEA) expanded cooperation on Sodium-cooled Fast Reactor (SFR) prototype development through a Memorandum of Understanding (MOU) signed by former DOE Assistant Secretary for Nuclear Energy Dennis R. Spurgeon, former CEA Chairman Alain Bugat and JAEA President Toshio Okazaki. [1] The MOU established a collaborative framework for the three research agencies (hereinafter the "participants") to jointly cooperate with the ultimate goal of deploying sodium-cooled fast reactor prototypes.

In signing the MOU, each of the parties affirmed its intent to develop advanced fast reactor prototypes according to its respective national program's objectives, and recognized that each country's individual development of SFR technology should not be duplicative. The participants entered into the MOU because of their common interest in developing SFRs in roughly the same timeframe and the recognition that technical expertise, resources and infrastructure required to deploy sodium-cooled fast reactor prototypes could be shared in a mutually beneficial manner.

This paper summarizes the progress made under the MOU and outlines one approach to effectively supporting infrastructure activities needed to deploy initial SFR prototypes and coordinating future technology development with the long-range research and development collaboration being performed under the Generation IV International Forum (GIF). It aims also to do so in a complementary fashion to facilitate the subsequent commercialization of SFR technology.

Recently, the U.S. fuel cycle research and development program has shifted from a near-term technology deployment program to a long-term, science-based research program. As a result, the U.S. is not currently pursuing the development of a commercial SFR prototype within the next two decades. [2]

II. BACKGROUND

The U.S., France and Japan also cooperate under the GIF which furthers the research and development of future nuclear energy systems. The United States first proposed the Generation IV concept in 1999 and the Generation IV International Forum (GIF) was created when Argentina, UK, Canada, Korea, Japan, Brazil, France and South Africa signed the GIF charter in July 2001. Since then, Switzerland, EURATOM, China and Russia have also signed the GIF charter.

In this framework, six next generation reactor types were selected in July 2002, which include the Gas-cooled Fast Reactor (GFR), Lead-cooled Fast Reactor (LFR), Molten Salt Reactor (MSR), Sodium-cooled Fast Reactor (SFR), Super Critical Water Reactor (SCWR) and Very High Temperature Reactor (VHTR). The progression of R&D activities for these reactor designs is divided into three phases. The first is the *viability* phase, where the principal objective is to resolve key feasibility and proof-of-principle issues. The second phase is the *performance* phase, where the key subsystems (such as the reactor, recycling facilities or energy conversion technology) need to be developed and optimized. The third phase is the *demonstration* phase, which has a number of options depending on the nature of the participation of industry, government, and even other countries in the project. The scope of Generation IV R&D is focused on the viability and performance phases. [3]

In the case of the SFR, EURATOM, France, Korea, United States and Japan signed the SFR system arrangement in 2006. Russia and China joined as observers. In March 2009 China signed the system arrangement and is now a participating country.

In 2006, major steps towards SFR development were taken in three of the participating countries as shown in Figure 1. In January 2006, the French president announced a national project which includes a fourth generation prototype reactor operation in 2020; SFR is thought to be a strong option for this prototype reactor. [4]

In February 2006, the United States proposed the Global Nuclear Energy Partnership (GNEP). GNEP has grown to an international framework with 25 partner nations in pursuing the expansion of clean, sustainable, nuclear energy worldwide in a safe and secure manner, while at the same time reducing the risk of nuclear proliferation. [5] The U.S., France and Japan also cooperate within the framework of GNEP. As part of the domestic GNEP program, the U.S. pursued the SFR for near-term deployment as part of a closed fuel cycle.

In Japan, “Feasibility Study on Commercialized Fast Reactor Fuel Cycle Systems” was conducted from 1999 to 2006. Based on the feasibility study, “Fast Reactor Cycle Technology Development Project (FaCT)” which targets a demonstration SFR plant construction in 2025 has been activated since April 2006. [6]

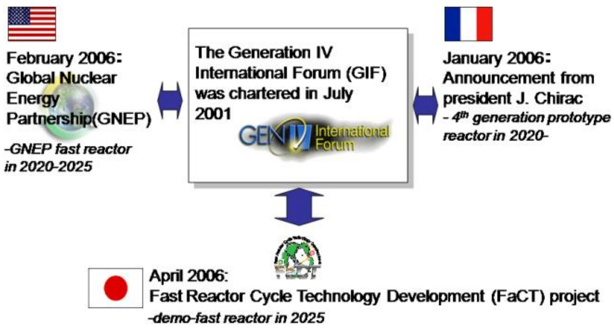

Figure 1: Outline of SFR Development Circumstances

III. SUMMARY OF ACTIVITIES UNDER THE MOU

Section III provides a summary of cooperation progress [7] achieved by the participants in the first year of the MOU.

III.A. Overview of the Memorandum of Understanding

As stated in the signed MOU, each participating country was committed, as part of their national programs, to developing SFRs to advance their respective countries’ intention of building demonstration/prototype (hereinafter called “prototype”) reactors within the next two decades toward the ultimate goal of commercial deployment. Therefore, the MOU initially focused on coming to a common understanding of the mission and requirements for an SFR, on various fuel types for a fast reactor system, and on how each country’s infrastructure, whether existing or proposed, could support fast reactor technology development.

Under the MOU, the participants shared the intention to outline a collaborative framework, review the reactor design criteria, and hold workshops and discussions to reach common recognition on reactor requirements, toward the ultimate goal of deploying SFR prototypes through an efficient collaborative process.

In addition, the participants explored options for leveraging the use of existing, new or refurbished support facilities for component testing, fuel development, and safety testing.

The work conducted under the MOU directly addressed one of the GNEP objectives: "To develop, demonstrate, and in due course deploy advanced fast reactors that consume transuranic elements from recycled spent fuel." [5] Repeated recycle in fast reactors was considered necessary to meet the overall GNEP waste management and proliferation objectives. Furthermore, fast reactor recycle would extend uranium resources.

The work activities under the MOU were organized into seven tasks. Task leads were designated from each participant to conduct the work activities associated with each task. The following shows the scope of each task.

(1) Establishing design goals and high level requirements for the prototypes.

(2) Defining common safety principles.

(3) Discussing the power level and configuration of sodium-cooled (loop and pool) fast reactor.

(4) Preliminarily comparing oxide and metal fuels and assessing the advantages and disadvantages of each.

(5) Discussing a common strategy about fuel facilities needed to provide start-up fuel to the prototypes.

(6) Identifying key technical innovations to reduce capital, operating and maintenance costs.

(7) Identifying test and support facilities and establishing a plan for securing the infra-structure needed to support materials, components and safety testing for the prototypes.

In addition, the participants exchanged information on their national programs in order to begin to develop target dates for prototypes to be used for planning purposes. This addresses one of the areas of cooperation from the MOU: "discussing a draft schedule of target dates for prototypes, including possible initial reactor start-up and full power operations to use as a planning basis; this schedule should be consistent with the national programs of the participants' countries."

III.B. Design Goals, Safety Principles and High Level Requirements (Task I & II)

The participants developed mission objectives for a generic concept, which was called the AFR (Advanced Fast Reactor). The AFR has the following five mission objectives:

(1) Demonstrate TRU recycling while generating electricity, thereby demonstrating sustainable electricity generation.

(2) Demonstrate fast reactor safety.

(3) Demonstrate design features for cost reduction and financial risk minimization.

(4) Provide capability for fast spectrum irradiations.

(5) Demonstrate reactor safeguards and security.

The primary mission of the first AFR prototype is to demonstrate the waste management and resource utilization benefits through the repeated recycle of transuranics, while generating electricity.

The transmutation of TRU is accomplished by fissioning and this is most effectively done in a fast neutron spectrum. Therefore, the AFR will be a fast-spectrum reactor. Sodium is the most proven coolant for fast reactors and was selected as the coolant. Multiple prototypes may be required to fulfill all mission objectives and support commercialization.

Task I and II were combined and entailed discussions among U.S., Japanese, and French experts leading to a draft document that provides high level requirements for a SFR prototype, together with the top level safety design principles and objectives. The Electric Power Research Institute (EPRI) document: *Advanced Light Water Utility Requirements Document* was used as a starting point for the design goals discussions. Goals or requirements that are specific to one country were identified and highlighted. In addition, the document: *Requirements for a Standard Commercial Advanced Burner Reactor* generated by the U.S. was also considered. To the extent practical, differences between the requirements for the prototype and future commercial plant were identified. In the area of safety design, discussions focused on defining a set of common safety principles to guide the design selection process, including identification of key safety design goals and quantification of reactor/plant safety performance requirements.

III.C. Power Level and Reactor Configuration Studies (Task III)

Technical specialists in Japan, France, and the U.S. compared pool and loop configurations of fast reactor plants. Discussions focused on understanding the characteristics of pool and loop SFR plants and generating a list of the similarities and differences of these two plant configurations and also understanding the innovations that can be introduced into the plants to improve the pool and loop concepts.

A criteria matrix was developed and discussions were held to facilitate comparisons and reach consensus. The criteria matrix was completed for innovative pool and loop plants to understand the improvements that can be made to these systems to improve safety, reliability, and economy.

Because the U.S. and France do not have a specific design for the AFR like the Japanese JSFR, the U.S. and France started with the high level requirements generated in Task I & II (discussed in Section III.B) and then generated a list of the main systems and components that fulfill those requirements. The high level requirements were grouped into three areas as agreed to by the participants:

- Safety and Investment Protection
- Reliability, Operability, and Maintainability (Fabrication and Construction, Inspection and Repair)
- Economics and Availability

For each requirement, the design features that contribute to fulfilling that requirement were listed and compared.

Regarding the power level of SFR prototypes, the participants are evaluating initial plant ratings ranging from about 100 to 750 MW electric.

III.D. Sodium-cooled Fast Reactor Fuel Type Comparison (Task IV)

This task provided an assessment of advanced SFR fuels needed for start-up fuel and transmutation (or minor actinide (MA) bearing) fuels. The comparison assessed the current state of understanding of the primary fuel options as well as an assessment of the fabricability, steady-state performance, off-normal performance, and the ability to recycle potential TRU fuel forms. It was not the intent of this effort to make a selection of a particular fuel form but to provide the needed basis and data for a fair comparison of fuel types and associated fuel cycles or identify the areas where data is lacking.

This task included two primary efforts. First, because the fuel cycle strategy differs between each participating nation, a description of the current fuel cycle strategy was provided from the perspective of fuel selection including a summary of the major features of the concept prototype SFR fuel and core design. Second, the participants identified areas to be evaluated during the fuel selection process, including performance, high burnup capability, licensing criteria, fabrication, and recyclability.

III.E. Start-up Fuel Fabrication Requirements and Facility Options (Task V)

The national strategies of the United States, Japan, and France were identified and the possible strategies for obtaining start-up fuel for a prototype SFR in each of the three nations were described. This activity identified possible areas of cooperation and harmonization to achieve the most cost effective strategy. At that time, the three countries had similar goals, development schedules, and deployment time-tables including:

- Fabrication capacity
- Start-up fuel without minor actinides (*i.e.*, using conventional fuels)
- Schedules for 2017-2030
- A lack of existing facilities to fully address the needs
- Mixed oxide fuel is a strong option for the participants

As noted earlier, the current U.S. program has shifted its focus and timetable from near-term fast reactor deployment to long-term fuel cycle research.

III.F. Technology Innovations for SFR Cost Reduction (Task VI)

Cost reduction for SFR technology is an important goal in each participant's domestic reactor technology development program that supports a long-term commercialization of the technology. Research and development activities would include:

- innovative technologies to reduce the capital cost of the reactor plant systems and
- innovative features to improve the reliability, maintainability, and longevity of the reactor plant systems that impact on operating costs.

This task identified the predominant cost reduction technologies being pursued by each country's program and potential research and development activities of common interest.

This work was performed in a three-step process. First, a list of innovative features or technologies being developed by each party was produced; this included an indication of the relative priority and near-term funding plans for research and development. Second, these documents were exchanged, specific technologies of common interest were identified, and a consensual evaluation was conducted of the relative promise and development time of each innovation. The technology list was prioritized based on both demonstration timing (near-term) and maximum benefit (long-term). Third, ideas for collaborative projects and/or exchange of key development data were recommended.

III.G. Infrastructure Collaboration (Task VII)

This task followed a strategic plan that consists of the following steps:

(1) Identify the research and development that is needed to develop SFR prototypes.

(2) Identify existing infrastructure that can be used to conduct the needed research and development.

(3) Identify the gaps between the needed research and development and the capabilities of the existing infrastructure.

(4) Define infrastructure projects that could be used to bridge the gaps.

(5) Decide and agree on implementing these projects.

Infrastructure projects have been identified to fill gaps (Step 4). These include a critical facility, an experimental reactor for transient testing, and sodium loops for component testing. The decisions on proceeding with specific infrastructure collaboration projects are being considered and the necessary implementation agreements will be developed in the future (Step 5). Infrastructure collaboration will be an ongoing activity. Each step in the strategic plan will be revisited as work proceeds and the participants evaluate their progress in the development of SFR prototypes.

IV. SFR HARMONIZATION

Two aspects of international SFR cooperation are shown in Figure 2. For SFR development, since most of the experimental and prototype fast reactors have already been shutdown, international collaboration using residual resources is very important. In Japan, there exist Joyo and Monju. Their availability for fast neutron irradiation is now getting more and more important because other reactors like French Phenix and US EBR-II have been shutdown. The US has the Transient Reactor Test facility (TREAT), currently in shutdown, for potential future transient irradiation test and Japan is strongly interested in it.

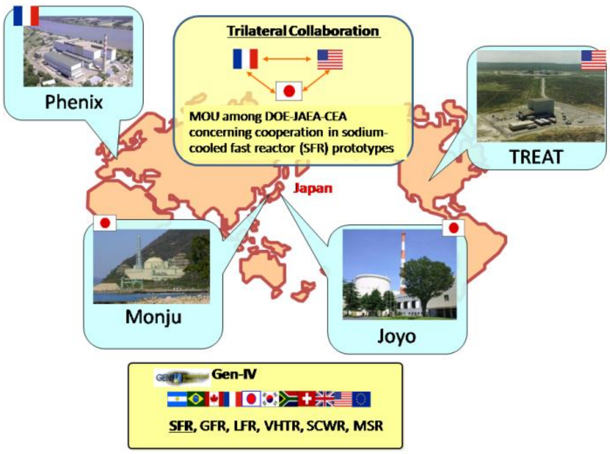

Figure 2: Overview of SFR International Cooperation

In the case of sodium component development and near term fuel development, most of them are based on rather conventional technologies even if new designs include some advanced parts and the component scales are larger than that of conventional ones. The historical experience gained by the US, France and Japan in their SFR development programs is extremely important and provides a mature technology basis for future collaboration. From the view point of collaborative utilization of R&D facilities, US, France and Japan have major facilities which could be utilized for large-scale sodium component development and fuel development tests (*e.g.* irradiation tests, transient overpower tests). Considering the above reasons, the participants chose to collaborate in accordance with the MOU described earlier.

The participants are also engaged as part of the GIF initiative. The GIF provides wider international collaborative framework involving several countries. This framework is thought to be suitable for broad and long-term R&D items like advanced fuel development and advanced energy conversion systems. In particular, the SFR System Arrangement has the objective to plan and carry out the research and development work necessary to establish the viability and to optimize the performance of the SFR System, and to facilitate (but not to undertake) the eventual demonstration of the SFR System. The Generation IV goals are shown as follows:

<Sustainability>

(1) Generate energy sustainably, and promote the long-term availability of nuclear fuel

(2) Minimize nuclear waste and reduce the long term stewardship burden

<Safety & Reliability>

(3) Excel in safety and reliability

(4) Have a very low likelihood and degree of reactor core damage

(5) Eliminate the need for offsite emergency response

<Economics>

(6) Have a life cycle cost advantage over other energy sources

(7) Have a level of financial risk comparable to other energy projects

<Proliferation Resistance & Physical Protection>

(8) Be a very unattractive route for diversion or theft of weapons-usable materials, and provide increased physical protection against acts of terrorism

The Generation IV scope includes a wide range of systems with various coolants (gas, sodium, lead, super critical water) and fuel types (oxide, metal, carbide, molten salt). In the case of the Generation IV SFR, the scope includes advanced fuels and advanced energy conversion systems like carbide fuel and super critical carbon dioxide Brayton cycle. These advanced technologies have not accumulated enough experience in the past or existing SFRs to demonstrate a sufficient level of technical maturity and are more relevant to the feasibility or performance phases. Therefore these and similar advanced technologies are considered to be suitable to the Generation IV framework and collaborative development of those advanced technologies will contribute to strengthening SFR potential as a future generation system.

It is prudent for the three countries to explore various approaches to continue effective collaboration, consistent with each of their national programs. Figure 3 depicts one model for future cooperation that includes evolutionary technology development activities, based on relatively mature technologies focused on cost reduction along with mutually beneficial infrastructure development and use. This approach would be particularly useful in supporting the deployment of demonstration facilities with the potential to accelerate basic SFR technology development as well as contributing to and informing the longer-term research efforts under the GIF. A new intergovernmental agreement among the three countries, building upon the MOU, would be needed to fully implement this approach.

The longer-term and broader research and development focused on viability and performance is more suitable to the GIF framework. The U.S., Japan, and France will continue to support research under the GIF SFR system arrangement. The System Arrangement recognizes that research in this area will be pursued on a bilateral or multilateral basis.

In particular, the U.S. will continue to be fully engaged in the GIF SFR activities, along with other bilateral or multilateral international arrangements, pending any future decisions to resume the pursuit of a domestic prototype fast reactor in the U.S.

France and Japan, will, on their side, also continue to be fully engaged in the GIF SFR activities, all while pursuing their national programs to construct prototype or demonstration fast reactors, which includes investigating possibilities for multi–lateral cooperation.

Although the future deployment timetable for a U.S. fast reactor is uncertain, the participants recognizing the importance and effectiveness of the trilateral framework, intend to analyze the national plans and milestones, along with the results from the seven tasks conducted under the trilateral MOU, and consider various options to enhance complemen–tarities among them in subsequent collaborations.

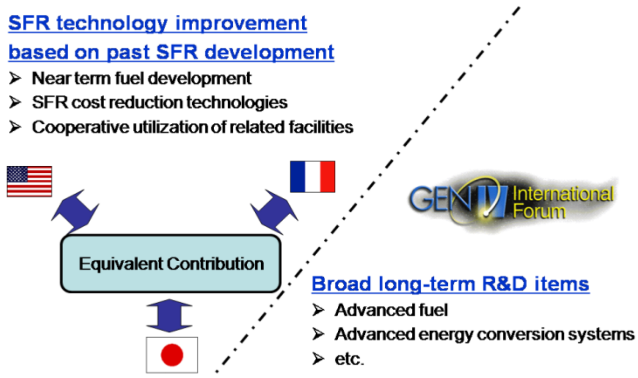

Figure 3: Harmonization of International Projects

V. CONCLUSION

The DOE, CEA and JAEA which participate in the GIF SFR activities have been cooperating on the development of SFR prototypes through the MOU since January 2008. The MOU initially focuses on reaching to a common understanding of the mission and requirements for an SFR, comparing various fuel types of a fast reactor system, and assessing each country's infrastructure, either existing or proposed, that could support fast reactor development. Although the United States has recently suspended its plans for the prototype fast reactor construction within the next two decades, such collaboration would be useful in supporting demonstration facilities with the potential to accelerate basic SFR technology development. It would also contribute to enhancing a long-term SFR research and development under the GIF framework involving a broader array of countries.

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